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(54) Method and apparatus for engine analysis

(57) Method and apparatus for analysis of engines analyses digitised input signals from for example engine injectors and compares this digital data with the corresponding values of a digitised template or comparison signal. Compliance or divergence between the digitised signal values is indicated in bar graph form.

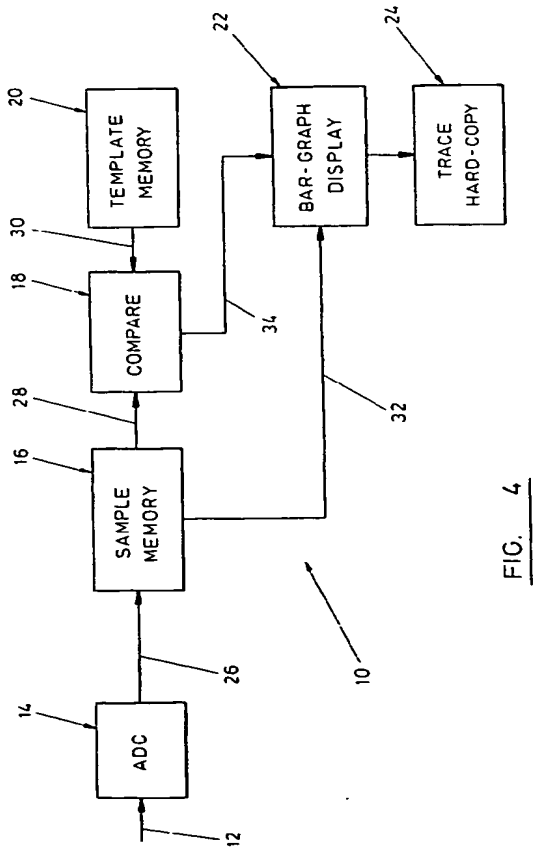

FIG. 4

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Description

This invention relates to a method and apparatus for engine analysis applicable to the electrodynamic analysis of electronic signals derived from an engine. An example of the application of the invention is to the analysis of the operation of a spark-ignition internal combustion engine by analysis of electrical signals derived from the spark ignition system. However, the invention is applicable to the analysis of compression ignition engines. Indeed, certain broad aspects of the invention are applicable to the analysis of signals relating to the operation of any rotary equipment, whereby the operation of the equipment can be analysed, particularly by reference to and by comparison with expected operating parameters such as corresponding signals relating to the engine or other equipment when operating in substantially new condition. In this way, a measure can be obtained of the degree of divergence of the equipment from its ideal operating condition as a result of use and wear etc.

An example of an input signal which may be analysed in accordance with the principles of the present invention is an electrical wave form derived from the spark ignition system of an internal combustion engine. Examples of other input signals and waveforms to which the present invention is applicable are electronic control unit signals, and relay switching (distributor-type ignition systems) signals. These are examples of time-based signals for analysis. In addition, as examples of signals in which analysis would be performed on a frequency basis are signals derived from vibration diagnostic equipment, such as the apparatus disclosed in our copending and unpublished application GB 9501380.1 (P52555GB); and oscillator outputs relating to frequency based gas sensing (such as may arise from sensing gas pressures in the crankcase or exhaust system of an automotive or other engine), or shaft encoder outputs for rotating machinery in which, for example, the encoder output frequency is dependent upon the rotational velocity of the shaft. As an example of signals where the basis of comparison is amplitude, there are power supply ripple voltages, such as might be obtained from the alternator of an automotive vehicle, and the battery charging current of such a vehicle.

Conventionally, an input wave form from the spark ignition system of an internal combustion engine has been analysed by visual techniques including the use of a suitable display on a cathode ray tube, whether in analogue form for instantaneous visual analysis by a trained technician, or by digital analysis, digital recording, and subsequent simulated analogue display of digitised data, in accordance with the teachings in European patent EP 08 13 53B (Bear).

The digital analysis, recording and subsequent display in simulated analogue form of the above-mentioned prior patent provide the advantages of flexibility of processing of the data prior to visual display, but is inherently subject to the shortcomings of visual assessment techniques, namely the limitations of any visual assessment technique, these relating to the observer's own personal visual assessment capabilities, which vary from person to person. Moreover, such an assessment is inevitably somewhat superficial and lacks the attention to detail which would clearly be beneficial if the remedial steps to be taken following such an assessment are to be carried out with the level of precision which can be realised when modern servicing techniques are utilised to their fullest extent.

There is disclosed in US 5,387,870 (Knapp et al) a method and apparatus for feature extraction from internal combustion engine ignition waveforms. In this apparatus a processor means determines in real time, times corresponding to positions along an ignition wave form corresponding to firing time, beginning of dwell interval, next firing time etc, and real time values corresponding to firing peak height, firing line duration etc. These values are compared with fixed threshold values so that anomalies can be determined. No comparison is provided between the input signal and a corresponding comparison or template signal. This disclosure corresponds in its main substantive elements with the functions provided by presently available automotive test equipment in which an input waveform is compared with pre-stored data representative of the limit values (or threshold values) of the relevant waveform. However, no means is provided enabling a convenient and effective comparison of the actual input waveform with the appropriate form of that wave if in its ideal condition or format.

US patent 5,119,315 discloses a method of correlating an input mass chromatogram with reference chromatogram data.

The prior art appears to contain no disclosure of a process whereby convenient comparison between an input signal from an actual operating machine can be analysed by reference to the corresponding waveform as produced by its ideal counterpart, for example the machine in new form.

According to the invention there is provided a method of analysis of engines and/or other rotary machines, and corresponding apparatus as setforth in the accompanying claims, and a corresponding apparatus for analysis of engines and/or other rotary machines as likewise defined therein.

In accordance with the teachings of the present invention we have taken the step forward of providing a method and apparatus which, in its embodiments, is capable of overcoming the above-identified shortcomings, this being achieved by eliminating the step of providing (as disclosed in the above-discussed EP specification) an analogue visual representation of the incoming signal, and substituting for this an electronic comparison step, which can be carried out on the digitised data which has hitherto been used as a basis for producing an analogue visual signal representation, such as a waveform.

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Thus, in accordance with the teachings of the present invention, an incoming signal is subjected to an initial digitising process. Then, the digitised data is subjected to an analytical step in which it is compared with data representing the basis for comparison, such as the wave form of the relevant signal produced by the equipment in its ideal form, such as the new equipment. Thus, the digitised data can be compared, item by item with the idea l data so as to produce an extremely detailed analytical result, enabling a far more refined comparison basis to be established than in the case of above-discussed prior US patent in which signal values are merely compared with threshold values.

We have realised that, in the case of such a step by step analysis process, the result which is required may well need only to be in the form of a yes/no answer since the comparison with the standard or "template" waveform in itself inherently takes care of the question of actual waveform.

Accordingly, the result of this analytical step may, in accordance with another aspect of the present invention be displayed or otherwise indicated in a variety of forms indicative, at a minimum, merely of whether or not compliance with the predetermined standard or template is achieved, and in some cases there may be provided in addition an indication applicable to the situation of non-compliance, of the degree of non-compliance, and possibly other characteristics of non-compliance. Such data can be indicated in a variety of visual or even audible ways.

Thus, in accordance with a broad aspect of the invention, there is provided a method and apparatus in which incoming test data is initially digitised. Then, some at least of the digitised data is compared with a standard. The result of the comparison step is then used to generate an indication of compliance.

The digitised data may of course be recorded and, after such recordal the comparison step may be carried out at any convenient time.

Likewise, the digitised data may be subjected to one or more data processing steps, for example in a computer system associated with the test apparatus, or remote therefrom, prior to or simultaneously with the analytical comparison step.

Embodiments of the invention provide the significant advantages of simplifying engine analysis, and thus correspondingly reducing the time taken and increasing the ease with which it is carried out. The person carrying out the test merely selects the appropriate template wave form, connects the engine to the test equipment to provide the input wave form for comparison purposes. The equipment then produces an appropriate indication of compliance or not. Suitable software may be provided which can provide, for example, a detailed statement of the remedial action required, which has been deduced from the comparison step by the data processing apparatus. Alternatively, the indication of compliance may provide (in the case of non-compliance) a graphical representation or diagram indicating the remedial action required eg a diagram of an injector pin requiring attention.

According to a further aspect of the invention it is envisaged that the template forming the basis for comparison with the digitised data from the input signal will be available in adaptive form whereby this basis for comparison is adaptable selectively to take account of, for example, progressive input signal changes recorded at time intervals and enabling corresponding time interval based analysis to be performed.

For implementation of the above-mentioned adaptive template, it is envisaged that the circuitry involved will embody neural networks (known per se) constructed to provide the facility for memorising or "learning" the waveform or waveforms to be used as a basis for comparison. Reference is directed to "Machine Design" (v 65 n21 pages 133/134 of October 22, 1993) by Patton, Alton; Swann, David and Arikara, Murali on the use of neural networks in Design (copyright Penton Publishing 1993). See also Electronic Design (v43, n9 page 38) by Ajluni, Cheryl on neural network/fuzzy - logic technology in which fuzzy logic is used to tune the neural networks (copyright 1995 Penton Publishing Inc).

In still further embodiments, the basis for comparison between the template data and the incoming data may be alternative parameters of the respective waveforms, including not only waveform and amplitude and frequency, and phase relationship, but also other variables including average values of particular ones of these parameters. Moreover, the comparison may be based on more than one waveform simultaneously sampled and compared. In the case of phase relationship, the analysis may be on the basis of a comparison between a particular chosen part of a waveform, for example a leading or trailing edge of a square wave.

Whereas in the embodiments described below there is employed a single waveform or signal in which a single function is plotted against time, it is envisaged that a chosen parameter need not be necessarily considered in relation to time, and the functions to be cross-related include not only time but also amplitude, frequency and phase. Moreover, multiple signals or waveforms may be simultaneously analysed in accordance with the method and apparatus of the invention.

Embodiments of the invention will now be described by way of example with reference to the accompanying drawings in which :-

Fig 1 shows a conceptual representation of a typical input waveform for the purposes of the present invention, based upon injector operation for a (compression)/sparkignition engine, the plot of injector valve voltage against time being in conventional analogue form;

Fig 2 shows the injector operation of Fig 1 represented likewise conventionally in analogue form but with the voltage dip indicated in terms of actual in-

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jector opening (A), held-open (B), closing (C), and held-closed (D) movements, the functions plotted being injector function (IF) or opening against time (T);

Fig 3 shows a corresponding bar graph representation of the injector functions plotted in Fig 2, these being indicated in bar form as produced, for example, by the "bar-graph display" and "trace hard-copy" functions of the apparatus of Fig 4;

Fig 4 shows, in block diagram form, circuits forming an embodiment of the invention and providing for analogue-to-digital input signal conversion, comparison of the digitised signal with a "template" signal and display of the result of the comparison, for example in bar-graph form;

Figs 5 and 6 show in vertically aligned relationship the injector function plot of Fig 1 constituting a "template" held in the template memory for use in the apparatus of Fig 4, and, positioned below it in Fig 6, a typical sample input signal in analogue form and corresponding to the injector operations of Fig 5, but with an indication (at 26) of an injector fault which requires to be identified by the apparatus of Fig 4;

Fig 7 shows in bar-graph form the result of the analysis of the signals of Figs 5 and 6 by the apparatus of Fig 4, and showing in the darkened portion 34 of the bar graph, and highlighted by signals 40, the error portion (E) of the injector function; and

Figs 8 to 10 and 11 to 13 and 14 to 17 show three groups of respective template and input wave forms together with the corresponding bar graphs showing the output of the comparison function.

The apparatus of Fig 4 is adapted to receive electronic input signals from a variety of sources, such as any suitable voltage or current pick up system capable of picking up voltage or current providing an indication of the operating function of any operating system of an automotive vehicle, for example the ignition system.

Thus, the voltage input signal for the apparatus 10 of Fig 4 can be represented by the voltage input signal shown in Figs 1 and 5. In these examples, for the particular injector function concerned, the voltage input signals, as shown in analogue form, are in what may be termed "ideal" form ie not including any fault suitable for identification by the apparatus of Fig 4. Of course, the presence or otherwise of "a fault" depends entirely on the basis for comparison.

Apparatus 10 comprises input signal connection means 12 coupled to an analogue to digital converter (ADC) 14, which is coupled to a sample memory function circuit 16. Further functional portions of the apparatus 10 comprise a comparison function circuit 18, a template memory function circuit 20 and a bar graph display function circuit 22 coupled to a trace hard copy function 24.

In Fig 4, the above-discussed functions have function couplings 26, 28, 30, 32 and 34. The function sequences comprise :

analogue to digital conversion
sample memory storage
compare to template memory
display in bar graph form
output to hard copy function

In Fig 4 also, the above-identified functions have been indicated in block diagram form. The corresponding electronic circuits to perform the functions individually are not in themselves the subject of this present patent application and circuits and apparatus capable of performing these individual functions will be matters of routine design work for a person of technical competence in this field.

ADC circuit 14 provides a known analogue-to-digital function. The circuit provides two analogue input channels, each with an input multiplexer for user signal selection. The input signal on each channel is amplified by a programmable gain amplifier, and an offset is introduced if necessary.

The resultant amplified input signal on each channel is processed by ADC 14. The sampling rate of the analogue-to-digital conversion step is fixed at a rate dependent upon the maximum signal frequency specified on that channel. Accordingly, the analogue-to-digital conversion is carried out at a reasonable maximum sampling rate in order to achieve, at all signal frequencies suitable for the apparatus 10, a sufficient number of data samples per waveform for the analytical steps which follow.

The digitised signal data from ADC circuit 14 is transmitted to sample memory 16 and stored. The memory function provided by circuit 16 has capacity sufficient to store data from both input channels such that, at the lowest input signal frequency sufficient data is captured to represent (in the case of internal combustion engine analysis) one complete engine cycle.

As shown at 32, sample memory 16 is coupled to bar-graph display 22 to enable a bar graph representation of the digitised input signal to be displayed and if necessary traced as a hard copy by function 24.

Template memory function circuit 20 performs a similar function to sample memory circuit 16, having stored therein, in digitised form, sample "standard" signals to be used as a comparison basis. These template signals can be selectively transmitted to comparison function circuit 18 for comparison with corresponding input signals derived from sample memory 16.

The single comparison function 18 thus receives signals to be compared from sample memory 16 and template memory 20. The comparison function is carried out on a point-by-point basis whereby deviations are identified likewise on the same basis. Circuit 18 produces an output through signal line 34 to bar graph display 22 whereby the result of the comparison steps can

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be displayed in bar graph form. Such display will now be discussed with reference to Figs 5 and 6.

Comparison of Figs 5 and 6 shows, in this illustrative simple example, a deviation between the two signals at the location identified at 26 where the injector has a fault in terms of excess hold time.

In an analogue display system in accordance with prior art teachings, it would be necessary for the user to identify area 26 merely from visual inspection of the analogue trace seen in Fig 6. Such identification would depend upon the user having clear recall of, (or the opportunity for cross-reference to) the standard trace shown in Fig 5.

In accordance with the method and apparatus of the present invention, the result of the comparison steps carried out by circuit 18 is produced in the bar graph form 28 shown in Fig 7.

As shown in Fig 7, bar graph 28 includes portions 30, 32, 34, 36 and 38 corresponding respectively to opening (A), and held-open (B), and fault indication (E), and closing (C), and held-closed (D) portions of the operating function of the injector.

The divergence between the digitised signals of Figs 5 and 6 at location 26 has resulted in the production of error indication portion 34 in bar graph 28 whereby the presence of such an error is instantly indicated. This is emphasised by the highlighting signals 40 which are simultaneously displayed.

As discussed above, bar graph 28 represents only one way of reproducing the result of the comparison function of apparatus 10, and other modes will be apparent to those skilled in the art on the basis of the above disclosure.

The trace hard copy function 24 enables the production of hard copies in the usual way for reference purposes.

Turning now to the embodiments of Figs 8 to 17, these figures show wave forms and corresponding bar graphs illustrative of the use of the method and apparatus of the invention for detecting and identifying differences in phase between input and template signals.

Thus, in Figs 8 and 9, the template signal of Fig 8 is disposed in relation to the input signal of Fig 9 so that the trailing edges 42, 44 of the respective wave forms are disposed in phase. Accordingly, the apparatus is arranged to show in the resultant bar graph 46 a uniformity of output which is indicative of no error-detection step, and thus the bar graph indicates the in-phase relationship of the above-discussed portions of the two wave forms.

In the wave forms of Figs 11 and 12, the template wave form of Fig 11 corresponds to that of Fig 8, and the leading edges of the input signal and of the template are likewise disposed in phase and are identified by reference numerals 44 and 42 as in the preceding embodiment. However, the trailing edge 48 of the input wave form is disposed (see Fig 12) out.of phase with respect to the corresponding trailing edge 50 of the input wave form of Fig 9. Accordingly, a corresponding "error" (E) is identified at 52 and flagged by signals 53 in the bar graph 54 of Fig 13.

It can thus be seen that the comparison function illustrated in Figs 8 to 13 represents a use of the method and apparatus of the invention for the detection and identification of phase differences not only between one input wave form and a corresponding template, but between such an input wave form and two or more wave forms used as a comparison basis.

In the embodiment of Figs 14 to 17, the trigger signal 60 of Fig 14 is employed to co-ordinate the in-phase relationship therewith of template waveform 62 in Fig 15 whereby the phase-shift 64 between template 62 and input waveform 66 (being a median of a number of sampled input signals) is identified on bar graph 68 of Fig 17 as error signals 70, flagged at 72.

In this embodiment, the trigger signal 60 provides the phase coordination basis for the phase comparison function of the method and apparatus.

Claims

1. A method of analysis of engines and/or other rotary machines comprising :-

   a) providing input means to obtain an input signal related to a variable characteristic of the operation of a rotary machine;
   b) causing said input means to provide said input signal;
   c) digitising said input signal from said input means for analysis of said variable characteristic; and
   d) analysis of said digitised input signal to determine information relating to said variable characteristic;

   characterised by

   e) said step of analysis of said digitised input signal comprising electronic comparison of said digitised signal values with the corresponding values of a digitised template or comparison signal;
   f) said step of comparison comprising determining the degree of compliance or divergence between the relevant digitised signal values of said input signal and said comparison signal; and
   g) generating an indication of compliance or divergence of said signals.

2. A method according to claim 1 characterised by said step of comparison of said digitised signal values comprising comparing said digitised signal values on an item-by-item basis, and said step of com-

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pliance or divergence indication comprising indicating accordingly for items individually or in groups.

3. A method according to claim 1 characterised by said step of comparison of said digitised signal values comprising comparing averaged values of at least one parameter of said digitised input signal with corresponding averaged values of said digitised comparison or template signal.

4. A method according to any one of claims 1 to 3 characterised by said step of determining compliance or divergence being followed by a step of indicating said divergence (if any) by providing an indication of appropriate remedial action.

5. A method according to any one of the preceding claims characterised by the step of providing means to adapt said digitised template or comparison signal in accordance with progressive changes in said digitised input signal, and said method comprising the step of progressively adapting said template or comparison signal accordingly.

6. A method according to any one of the preceding claims characterised by said step of comparison of said digitised signal values comprising effecting said comparison step on the basis of at least one of the parameters of the input signal waveform selected from the group consisting of :-

Signal waveform
Signal amplitude
Signal frequency
Signal phase
Signal phase of a chosen part of the input waveform.

7. A method according to any one of the preceding claims characterised by the sampling rate of said analogue-to-digital conversion step being fixed at a rate related to the maximum frequency of said input signal such that a sufficient plurality of data samples per waveform are obtained at said maximum frequency, for said step of comparison of said digitised input and template signals.

8. A method according to any one of the preceding claims characterised by said step of indicating said degree of compliance or divergence of said digitised signal values comprising displaying said degree of compliance or divergence in bar graph form.

9. A method according to any one of the preceding claims characterised by the step of establishing a phase-coordinated relationship between said input and said template or comparison signals by means of a trigger signal.

10. A method according to any one of the preceding claims characterised by said step of comparison of said digitised input signal with the corresponding values of a digitised template or comparison signal comprising employing at least two digitised template or comparison signals as a basis for comparison.

11. A method according to any one of the preceding claims characterised by said method being adapted for the analysis of internal combustion engines by said step of providing said input signal comprising providing said signal from a signal source selected from the group consisting of :-

a) spark ignition system signals;
b) electronic control unit signals;
c) transducer-generated vibration signals;
d) transducer-generated gas pressure sensing signals;
e) shaft encoder signals;
f) alternator ripple signals;
g) transducer - generated acoustics signals;
h) battery signals.

12. A method of analysis of engines and other rotary machines comprising comparison of an input signal related to a variable characteristic of the operation of a rotary machine with a corresponding template or comparison signal characterised by the step of progressively adapting said template or comparison signal in accordance with progressive changes in said input signal.

13. A method of analysis of engines and other rotary machines comprising providing an input signal related to a variable characteristic of the operation of a rotary machine and comparing said input signal with a corresponding template or comparison signal and generating an indication of compliance or divergence of said signals, said compliance or divergence being indicated in bar graph form.

14. Apparatus for analysis of engines and/or other rotary machines comprising :-

a) input means to obtain an input signal related to a variable characteristic of the operation of a rotary machine;
b) analogue-to-digital conversion means to digitise an input signal from said input means for analysis of said variable characteristic;
c) signal analysis means to analyse said digitised input signal to determine information relating to said variable characteristic;

characterised by

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d) signal value comparison means adapted to effect electronic comparison of said digitised signal values with the corresponding values of a digitised template or comparison signal; and
e) indicator means adapted to generate an indication of compliance or divergence of said input and template signals.

15. Apparatus according to claim 14 characterised by signal storage and retrieval means adapted to store and retrieve signals for use as said template or comparison signals.

16. Apparatus according to claim 14 or claim 15 characterised by said signal value comparison means being adapted to compare said digitised signal values on an item-by-item basis.

17. Apparatus according to any one of claims 14 to 16 characterised by said indicator means adapted to generate an indication of compliance or divergence being adapted to (in the case of divergence) indicate corresponding remedial action.

18. Apparatus according to any one of claims 14 to 16 characterised by said signal value comparison means being adapted to compare averaged values of at least one parameter of said digitised input signal with corresponding averaged values of said digitised comparison signal.

19. Apparatus according to claim 15 characterised by said signal storage and retrieval means being adapted to adapt said template or comparison signal in accordance with progressive changes in said input signal as a basis for comparison.

20. Apparatus according to any of claims 14 to 19 characterised by said signal value comparison means being adapted to effect comparison of said digitised signal values on the basis of at least one of the parameters of the input signal waveform selected from the group consisting of :-

a) signal waveform;
b) signal amplitude;
c) signal frequency;
d) signal phase;
e) signal phase of a chosen part of the input waveform.

21. Apparatus according to any one of claims 14 to 20 characterised by said analogue-to-digital conversion means having a sampling rate fixed at a rate related to the maximum frequency of the input signal intended for said apparatus, such that a sufficient plurality of data samples per waveform are obtained at said maximum frequency for the purpose of comparison of said digitised input and template signals.

22. Apparatus according to any one of claims 14 to 21 characterised by said indicator means comprising bar graph display means to indicate said degree of said compliance or divergence.

23. Apparatus according to any one of claims 14 to 22 characterised by trigger signal generation and input means adapted to generate a trigger signal for use in establishing a phase-coordinated relationship between said input and said template or comparison signals.

24. Apparatus according to claim 15 characterised by said signal storage and retrieval means being adapted to store and retrieve at least two digitised template or comparison signals as a basis for comparison.

25. Apparatus according to any one of claims 14 to 23 characterised by said apparatus being adapted for analysis of internal combustion engines, and said input means being adapted to provide a signal from a signal source selected from the group consisting of :-

a) spark ignition system signals;
b) electronic control unit signals;
c) transducer-generated vibration signals;
d) transducer-generated gas pressure sensing signals;
e) shaft encoder signals
f) alternator ripple signals.
g) transducer - generated acoustic signals;
h) battery signals.

26. Apparatus for analysis of engines and/or other rotary machines comprising :

a) input means to provide an input signal related to available characteristic of the operation of a rotary machine;
b) signal value comparison means adapted to effect electronic comparison of said input signal with a corresponding template or comparison signal;
c) means to adapt said template or comparison signal in accordance with progressive changes in said input signal.

27. Apparatus for analysis of engines and/or other rotary machines comprising :

a) input means to provide an input signal related to available characteristic of the operation of a rotary machine;

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b) signal value comparison means adapted to effect electronic comparison of said input signal with a corresponding template or comparison signal;
c) indicator means to generate an indication of compliance or divergence of said template signals;
d) said indication means comprising bar graph generation means adapted to display said degree of compliance or divergence in bar graph form.

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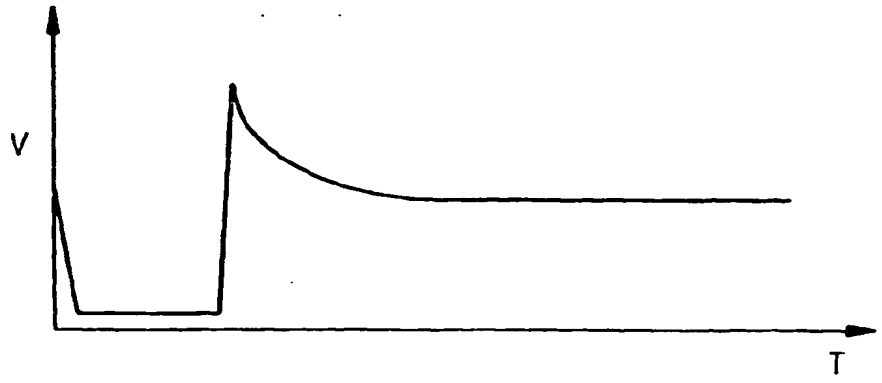

FIG. 1

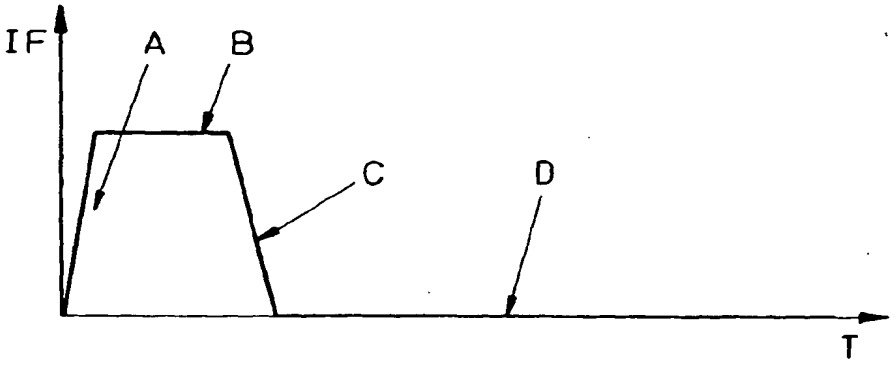

FIG. 2

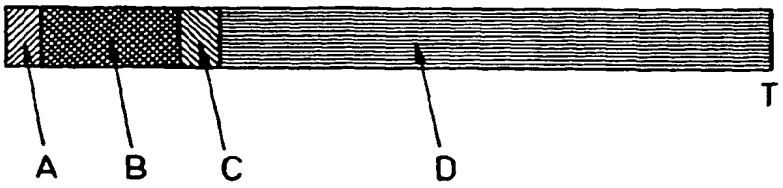

FIG. 3

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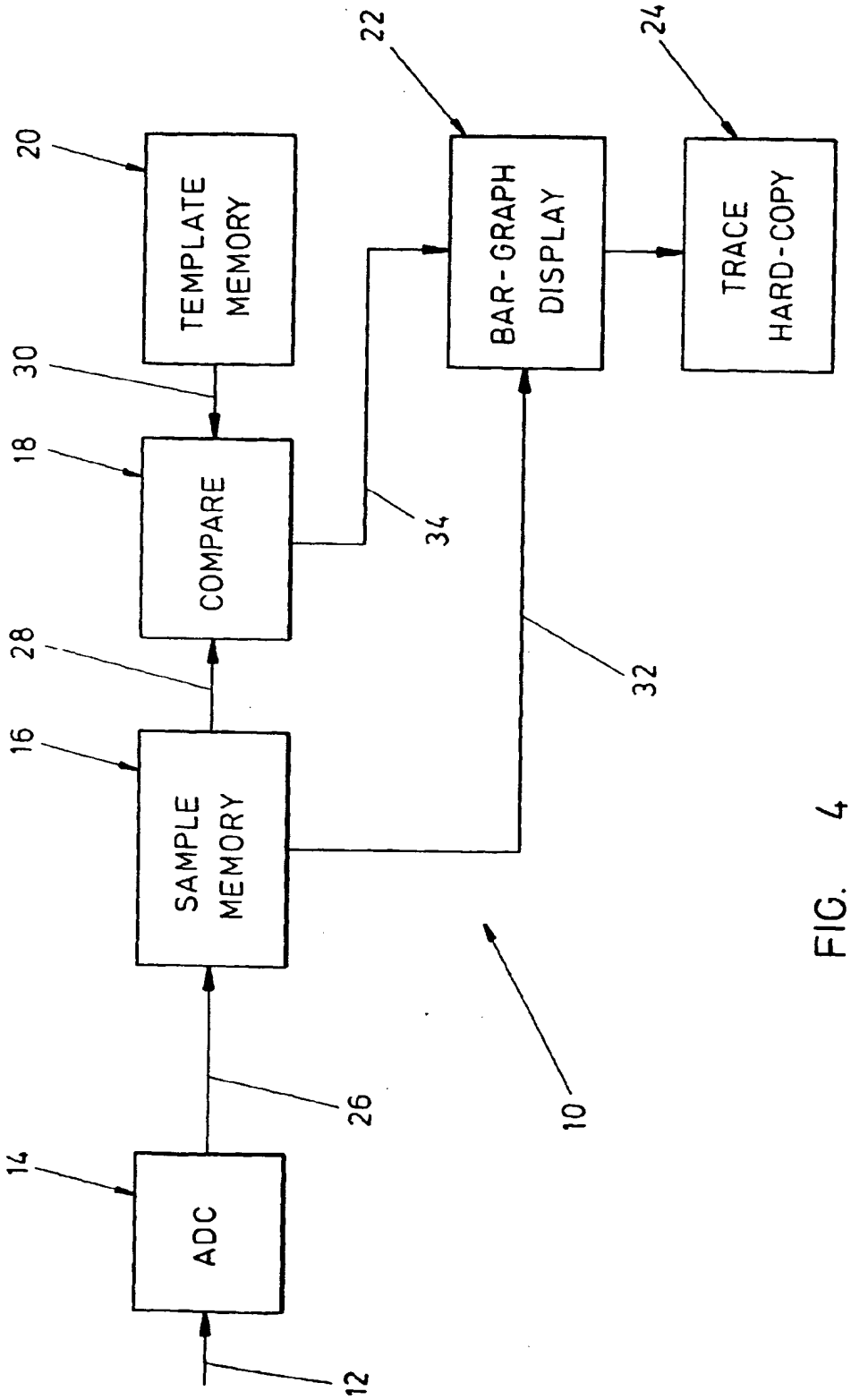

FIG. 4

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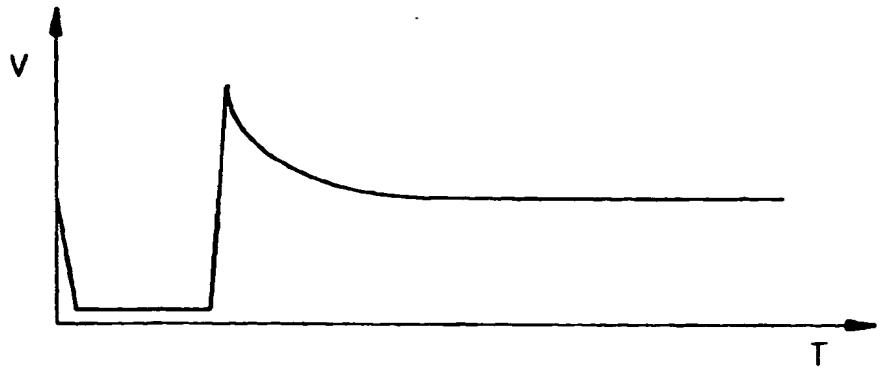

FIG. 5

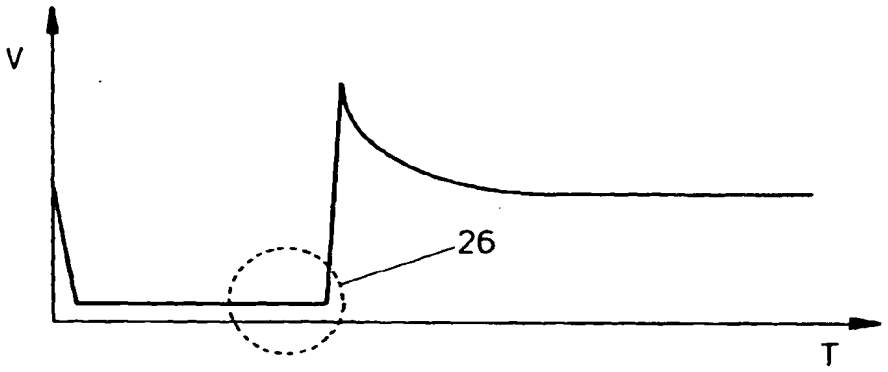

FIG. 6

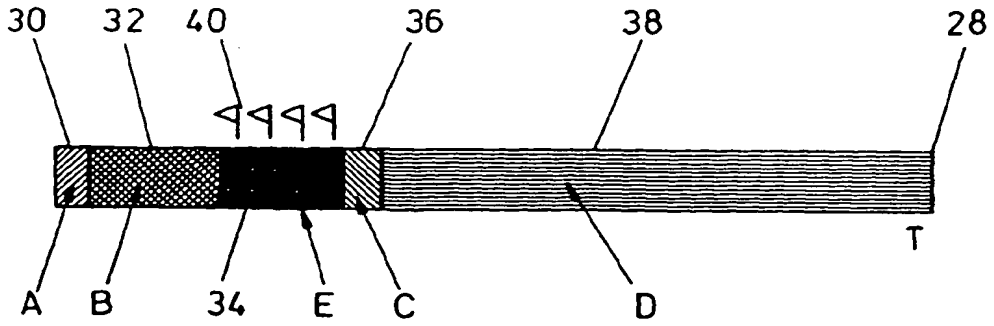

FIG. 7

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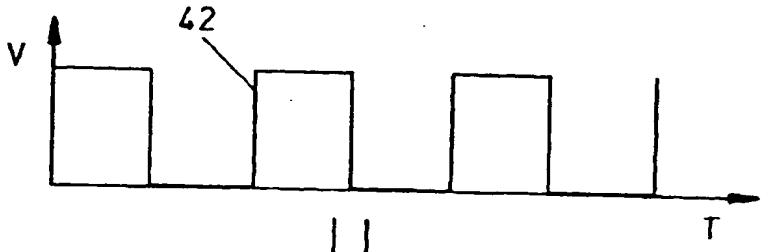

FIG. 8

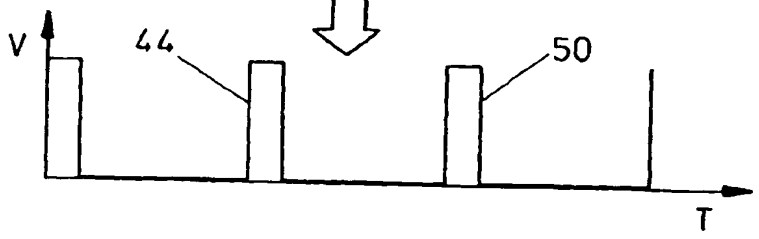

FIG. 9

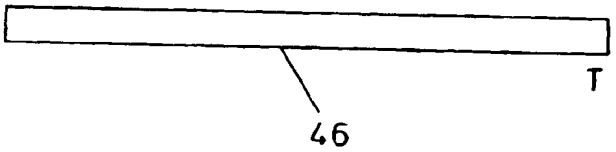

FIG. 10

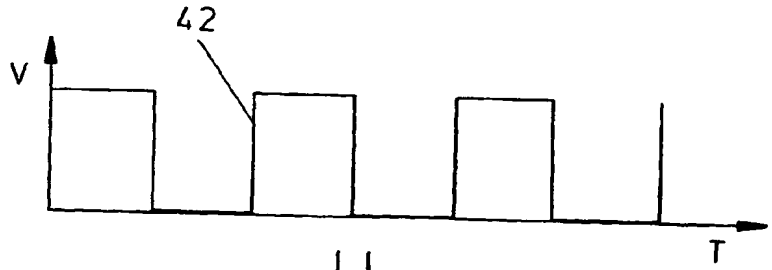

FIG. 11

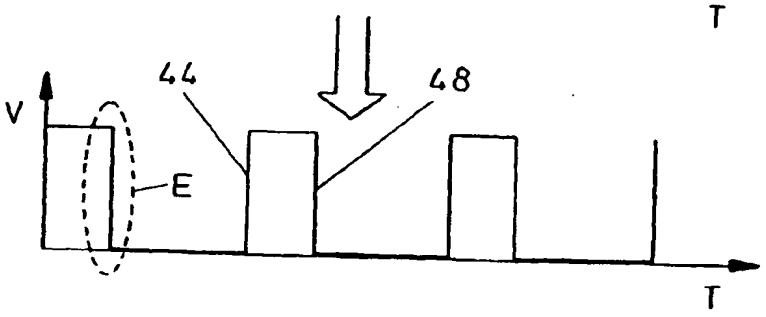

FIG. 12

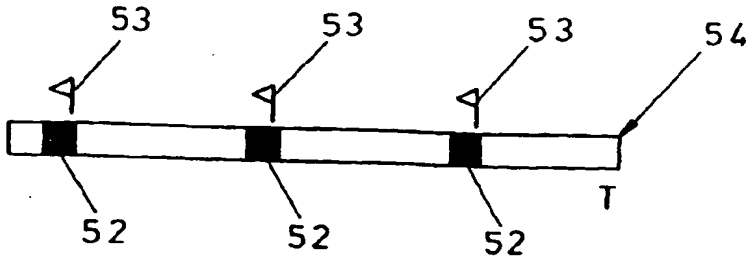

FIG. 13

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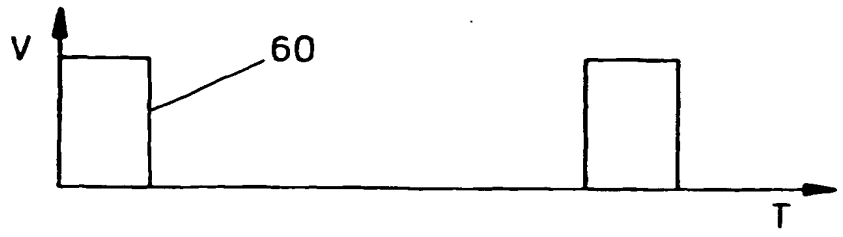

FIG. 14

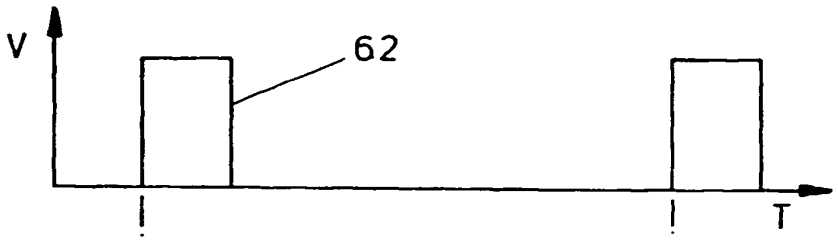

FIG. 15

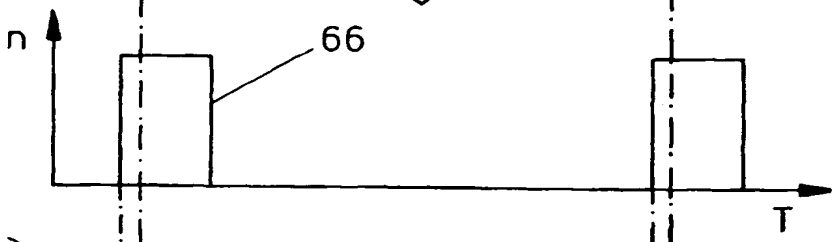

FIG. 16

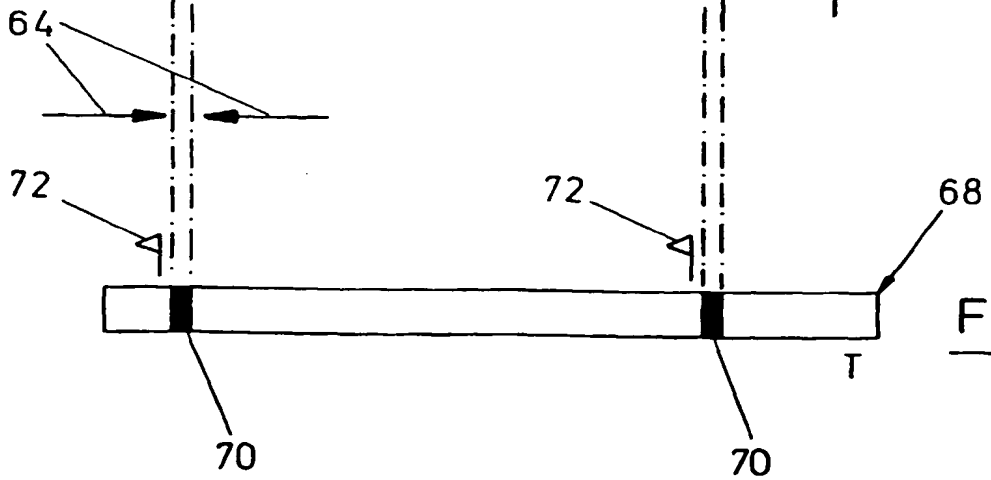

FIG. 17

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(54) Method and apparatus for engine analysis

(57) Method and apparatus for analysis of engines analyses digitised input signals from for example engine injectors and compares this digital data with the corresponding values of a digitised template or comparison signal. Compliance or divergence between the digitised signal values is indicated in bar graph form.

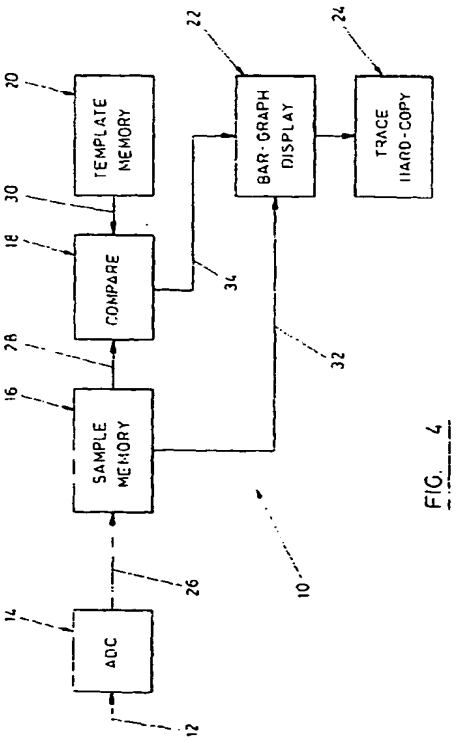

FIG. 4

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European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 96 30 1428

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	US 4 424 709 A (MEIER JR RAYMOND C ET AL) 10 January 1984 * abstract; claims 1-29; figure 1 *	1-3	F02B77/08
A	GB 2 135 061 A (FORD MOTOR CO) 22 August 1984 * the whole document *	1-3	
A	GB 2 248 110 A (ROLLS ROYCE PLC) 25 March 1992 * the whole document *	1-3	
A	DE 42 39 096 A (RENK AG) 26 May 1994 * abstract; figure 1 *	1	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

F02B
F02P

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	4 February 1997	Wassenaar, G

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